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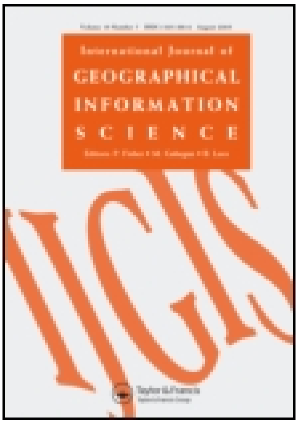

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This article focuses on the use of map-based multicriteria analysis to develop a negotiation support tool for land use allocation. Spatial multicriteria analysis is used to make explicit trade-offs between objectives and to provide guidance and feedback on the land use changes negotiated by the participants. Digital maps are the means of communication among workshop participants, and an interactive mapping device (the 'Touch table') is used as the interface. Participants are informed about the relevant trade-offs on the map and use this information to change the land use maps. The approach is tested during a negotiation session as part of the land use planning process of the Bodegraven polder, a peat meadow area in the Netherlands.

Keywords: interactive decision support; map-based multicriteria analysis; participatory land use planning

1. Introduction

Multicriteria analysis (MCA) provides well-established decision support tools for policy analysis with conflicting objectives (Belton and Stewart 2002, Janssen and Herwijnen 2007). Conflicts can arise not only from the various objectives of a single decision-maker but also from differences in objectives among various decision-makers. The aim of the methods may range from ranking of alternatives in order of attractiveness, clarifying conflict, to generating compromise solutions. Multicriteria methods can also be used if alternatives and/or objectives are spatial, as in spatial planning. This requires data on the geographical locations of alternatives, geo-referenced data on criterion values and, in many cases, a combination of multicriteria methods with a geographical information system (GIS). This combination is usually referred to as spatial decision support systems. GIS is used to produce thematic maps and to perform spatial operations. Multicriteria methods are used to translate these maps into value maps, optimal or compromise maps and rankings. Although multicriteria methods and spatial MCA are based on the same underlying concepts, addition of the spatial dimension leads to specific issues with regard to weights and standardization (Herwijnen and Janssen 2002).

The most straightforward use of spatial MCA is comparison and ranking of alternatives. Spatial MCA can be used not only to link policy priorities to rankings but also to provide insight into the spatial distribution of the performance of the alternatives. Examples of

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GIS–MCA combinations can be found in Recatalá and Zinck (2008), Lesslie *et al*. (2008), Pelizaro *et al*. (2009) and Janssen *et al.* (in press). Spatial multicriteria methods can also be used to generate an optimal solution for a specific preference structure from a large or possibly infinite set of alternatives. In other words, the optimal solution is created or 'designed' using techniques based on tools such as multi-objective linear programming (e.g. Cova and Church 2000, Aerts *et al*. 2003, Ananda and Herath 2008, Janssen *et al*. 2008, Santé-Riveira *et al*. 2008). As a special case of design methods, interactive optimization offers solutions to the planner in a number of steps where, after each step, the planner can change the conditions for optimization (e.g. Stewart *et al*. 2004, Janssen *et al*. 2008). Using optimization to generate the optimal solution requires that all objectives can be described in mathematical terms and incorporated in the routine.

The tool presented in this article builds on the use of spatial MCA for comparison and ranking. It uses results from MCA to support negotiations about land use change. The tool is interactive as it provides the negotiators with information on favourable exchanges of land use and provides feedback after each step. The MCA tool makes it possible to structure and aggregate the information in a way to make it suitable to support negotiation. Because it is interactive, it also leaves room for the negotiators to include considerations that were impossible to include in the formal specification of the problem. In developing the tool, special attention is given to the design of the maps used to support negotiation. In practice, effective use of maps is a difficult task for many people and the use of maps for evaluation is not a task most people are familiar with (Kraak and Ormeling 2003, Andrienko *et al*. 2007, Carton and Thissen 2009). The tool is applied within a land use planning process in the Netherlands. A large amount of information is available to support this process. Although relevant, there is too much information to be used in negotiation. Our multicriteria tool makes this information available in a format useful for negotiation. The interface allows for effective visualization of the MCA results.

This article focuses on the use of map-based MCA to develop a negotiation support tool for land use allocation. This article addresses the following research questions:

- Can map-based MCA be used to evaluate and communicate qualities of land use plans?
- Can map-based MCA be used to support negotiation on land use allocation?
- How do participants interact with the tool?

A short overview of existing tools is presented in Section 2. The use of map-based MCA to build a negotiation support tool is described in Section 3. The tool is demonstrated with a land use problem in the Netherlands (Section 4) and finally conclusions on its usefulness are provided in Section 5.

2. Map-based MCA

Recent applications of spatial decision support for land use planning integrate elements of MCA and GIS. This integration has contributed to the further development of tools for participatory spatial decision-making (Eastman *et al*. 1998, Janssen and Herwijnen 1998, Feick and Hall 2002, Malczewski 2006). However, the use of these tools in practice is not always successful (Uran and Janssen 2003, Goosen *et al*. 2007). The output of map-based MCA can play an important role in participatory spatial decision-making but is not always easy to handle and present to different groups of stakeholders. Although often helpful for participatory planning, maps can also be a source of conflict (Carton and Thissen 2009).

MCA provides numerous methods to evaluate, compare, rank and present the performance of decision alternatives on the basis of several criteria and/or objectives. GIS is used to map and present the performance of alternatives. Examples of the use of map-based MCA for evaluation, comparison, ranking and mapping of decision alternatives can be found in Janssen *et al.* (2005), Pettit (2005), Sheppard and Meitner (2005), Goosen *et al.* (2007), Santé-Riveira *et al.* (2008) and Pelizaro *et al.* (2009).

Map-based MCA tools can also be interactive with user-friendly interfaces that allow users to provide input and generate output in real time. An example of an interactive MCA tool to support negotiated land use allocation is described in Goosen *et al.* (2007). Several studies recommend interfaces to integrate geographical visualization and MCA (e.g. MacEachren and Brewer 2004, Andrienko *et al*. 2007, Bishop *et al*. 2009). An example is the interface developed by Bishop *et al*. (2009) to support forest management. The interface consists of a 3D display, that is, an aerial photography draped over an elevation model of the study area, navigation controls and a number of interactive sliders with which users can set and change parameters. The interface was used by stakeholders to change criteria weights interactively during a planning session and to see the effects of these changes in the 3D display. The sliders allowed users to set criteria weights and also to set constraints on the criteria outcomes. As one user moved one particular slider, for example, environment, a weighted forest suitability map was generated and displayed as 3D objects representing trees overlaid on the 3D landscape. Other sliders moved accordingly, depending on the aggregated MCA output.

Land use plans can also be generated in a more automated manner using optimization methods. These include algorithms to find the best solution to a given spatial decision problem that has been formulated in terms of mathematical models (Malczewski 1999). Common optimization methods are multi-objective programming algorithms, heuristic search/evolutionary/genetic algorithms and goal programming/reference point algorithms (Eastman *et al*. 1998, Malczewski 2006). Examples of interactive MCA-based approaches that use optimization methods are the raster-based Rural Land-Use Exploration System (Santé-Riveira *et al*. 2008) and a raster-based approach to support design of land use plans as described in Janssen *et al.* (2008).

More relevant to this study are map-based MCA tools for collaborative spatial decision support. These tools combine MCA–GIS with visualization tools and multi-user interfaces (e.g. touch-enabled screens), which are often facilitated by mediators (e.g. Feick and Hall 2002, Salter *et al*. 2009). For example, Pettit (2005) examined the application of a collaborative GIS–MCA tool in a scenario-building exercise with local planners to support the formulation of a sustainable scenario for Hervey Bay, Australia. The tool, called What if?™, is based on three components: land suitability, growth-analysis model and land-allocation model (Klosterman 1999). Other studies recommend visual displays that link maps and MCA to support group-based decision-making. The CommonGIS tool (Andrienko and Andrienko 2003, Andrienko *et al*. 2003) is a group-based spatial decision support system that links maps of decision options and dynamic statistical graphs that show MCA evaluation results. Voting techniques constitute other approaches for MCA-based collaborative decision-making (e.g. the Land-Use Planning Information System (Recatalá and Zinck 2008) or the 'Spatial Group Choice' (Jankowski and Nyerges 2001)).

3. Map-based MCA for negotiation support

MCA is a tool to address decision problems with conflicting objectives. MCA can compare a set of alternatives using one or more criteria to determine the performance of each alternative for the given objectives (Belton and Stewart 2002). When decision problems have a clear spatial component, an MCA method that incorporates this spatial aspect is needed: a spatial MCA. In a spatial multicriteria decision problem, the ranking of the alternatives is split into two steps: the aggregation of the spatial component and the aggregation of the criteria. These two steps can be carried out in different orders: first the aggregation of the criteria, then the aggregation of the spatial component, or vice versa (Herwijnen and Rietveld 1999, Herwijnen and Janssen 2002). The implementation of a spatial MCA as described in this article has the aggregation of the criteria as the first step and the spatial aggregation as the second step.

Spatial objects can be represented using a raster or vector data model. In a raster representation, all raster cells are ordered in rows and columns and share the same geometry. A vector representation differs from a raster representation in that a vector data set usually has diverse geometries. This has a consequence for the spatial aggregation, because different locations, lengths and or sizes have to be considered. When decisions are to be made on the level of spatial units with an explicit size and shape, such as parcels, watersheds and municipalities, a vector-based (polygon-based) decision support tool might be more appropriate than a raster-based tool. Furthermore, vector maps appear more realistic than raster maps, which can be an advantage for interactive tools (Janssen *et al.* 2008).

The capability of map-based MCA to identify trade-offs between objectives across spatial units can be used to incorporate MCA results in a tool that supports negotiations on land use changes. This section describes two polygon-based types of use of MCA results to support negotiation. The first type is implemented in the ‘best & worst tool’, which marks polygons (representing land parcels in our case study) that are very suitable or very unsuitable for each potential land use type based on their summed area. The second type is implemented in the ‘value trade-off tool’, which marks polygons that would profit from a change of land use based on their actual MCA value. With both tools, users can select and highlight polygons with MCA scores that are above or below user-specified thresholds. The use of the tools thus supports the selection of *high-value* polygons as those polygons that have an MCA score above a certain threshold or *low-value* polygons if the polygons have an MCA score below a certain threshold.

In general, the criterion values for each polygon are dependent on the type of land use in combination with other attributes such as soil type and water level. The influence of the attributes on the value of a land use is dependent on the type of land use. For example, high water levels will generate a high value for marshland but a low value for agriculture. As value and land use are now linked, a change in land use will change the value of the polygon changes and ultimately the total value of the plan. The relation between value and land use is the basis for the negotiation routine. In this way the value of each polygon is made dynamic. Equation (1) shows the calculation of the spatially aggregated value s of objective j and for all m polygons in an alternative; r_{mj} is the MCA value of objective j for polygon m and standardized on the area of polygon m. This basic equation is used in both tools:

$$S_j = \sum_{m=1}^{M} r_{mj} \tag{1}$$

The ‘best & worst tool’ defines the intersection T of the subset G with the highest and the subset B with the lowest MCA objective values. This intersection T contains the polygons that are potentially favourable for exchange. The polygon elements in subsets G

and B are selected based on the sum of the polygon areas. The user defines two threshold area sizes for each land use type: the area of high-value polygons and the area of low-value polygons to be visualized. This means that there will be $2 \times U$ subsets, where U is the number of land use types. For each land use type l, the area of suitable polygons is set by the users. This is threshold value i_{lg}. For each land use type l, a subset G_l with the high-value polygons will be selected from set P with all polygons. The set of polygons is defined as

$$P = \{p_1, p_2, \ldots, p_m\} \text{ for } m = 1, \ldots M \tag{2}$$

Set D contains the same polygons as P, but ordered in descending order by their MCA objective score s_j (see Equation (1) for s):

$$D = \{d_1, d2, \ldots, dm \mid s_j(d_1) \geq s(d_2) \geq \ldots \geq s_j(d_m)\} \tag{3}$$

Subset G contains Y elements from D, where the cumulative area of the polygons is smaller or equal to threshold i:

$$G_l(i) = \{d_1, d_2, \ldots, d_y \mid d \in D, s_j(d_1) \geq s_j(d_2) \geq \ldots \geq s_j(d_y) \wedge \sum_{d=1}^{y} h_d \geq i\} \tag{4}$$

The above procedure is repeated for the selection of the low-value polygons, then the subset D is substituted with subset A containing the polygons in ascending order by optimal MCA value. Threshold value is i_{lb}, the number of hectares with the lowest scores for land use type l:

$$A = \{a_1, a_2, \ldots, a_m \mid s_j(a_1) \geq s_j(a_2) \geq \ldots \geq s_j(a_m)\} \tag{5}$$

The definition of subset B, containing the low-value polygons, is comparable with the definition of the high-value polygons:

$$B_l(i_{lb}) = \{a_1, a_2, \ldots, a_y \mid a \in A, s_j(a_1) \geq s_j(a_2) \geq \ldots \geq s_j(a_y) \wedge \left(\sum_{a=1}^{y} h_a\right) \leq i\} \tag{6}$$

Figure 1a shows how the subsets G and B are visualized on a map.

The 'value trade-off tool' selects subsets that visualize possible trade-offs between two objectives linked to two land use types: land use a and b. Threshold u_{ga} defines the minimum MCA value of a polygon for land use type a to be a high-value polygon for that specific land use type. All polygons that have an MCA value for land use type a that is higher or equal to the threshold u_{ga} are in subset G_a. The threshold u_{gb} defines the minimum MCA value of a polygon for land use type b to be in subset G_b. Subsets B_a and B_b contain the low-value polygons for land use a and b, respectively. In this tool, the sets do not need to be ordered before creating the subset. The sets G and B are defined as

$$G_j(u_g) = \{p \in P \mid s_j(p) \geq u_{gj}\} \quad G \subseteq P \tag{7}$$

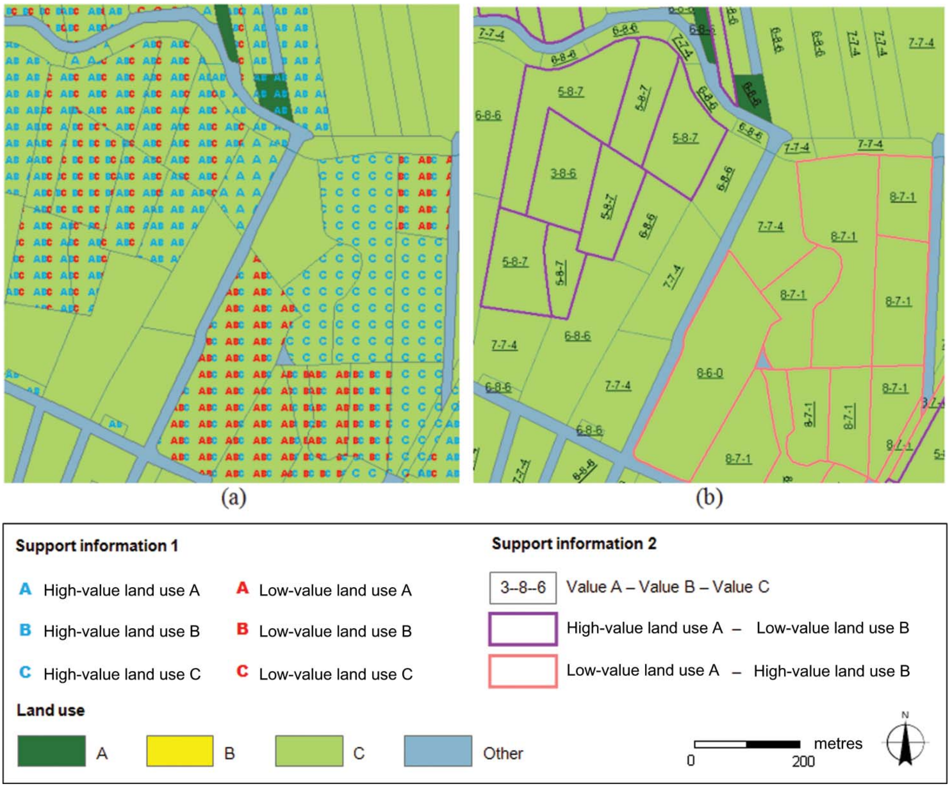

Figure 1. Results from two negotiation support tools: (a) the 'best & worst tool' and (b) the 'value trade-off tool'.

$$B_j(u_b) = \{p \in P \mid s_j(p) \leq u_{bj}\} \quad G \subseteq P \tag{8}$$

A trade-off set T is a subset of P representing polygons that are favourable for negotiation between a pair of land use types, such that high-value and low-value polygons for one land use type overlap low-value and high-value polygons, respectively, of a second land use. T thus contains polygons that are suitable for swap. A swap can be done between two land use types and is to be implemented on polygons within T. Let a and b be any two land use types from the set of L land use types. Hence $T \subseteq P$, $a \in L$, $b \in L$ and $a \neq b$.

Threshold i_l defines the number of elements of the sets with high-value and low-value polygons for the two land use types. For land use type a, the high-value polygons are in subset G_a and the low-value polygons are in subset B_a. For land use type b, the high-value polygons are in subset G_b and the low-value polygons are in subset B_b.

The overlap between high-value polygons for objective a and low-value polygons for objective b is defined as $G_a \cap B_b$. The overlap between high-value polygons for objective b and low-value polygons for objective a is the opposite case: $G_b \cap B_a$. Hence, the trade-off set (for land use a, land use b) is the union of both sets:

$$T_{ab} = (G_a \cap B_b) \cup (G_b \cap B_a) \tag{9}$$

In the 'best & worst tool', if more than two objectives are compared, the total set of polygons with trade-offs between all objectives is defined as

$$T = \bigcup_{a=1}^{j} T_a \tag{10}$$

Figure 1a shows results from the 'best & worst tool'; the polygons in subsets G_l are marked with blue characters and subsets B_l are marked with red characters. Three land use types are compared, but it is also possible to compare four or five land use types. The number of land use types that can be compared using this method is limited in practice because it is difficult to read more than three symbols at the time. Figure 1b shows results from the 'value trade-off tool'; the coloured polygon boundaries suggest possible exchanges between two land use types. Boundaries of the polygons that are potentially favourable for exchange are highlighted with a different colour for each land use type. The purple boundaries indicate that these polygons have a high value for land use a and a low value for land use b ($G_a \cap B_b$). The pink boundaries show the polygons that have a low value for land use type a and high value for land use b ($G_b \cap B_a$). The numbers in the polygons show the value of that polygon for the possible land use types (three land use types in this example). The background colour indicates the current land use of each polygon.

4. Negotiation support for the Bodegraven polder

4.1. The Bodegraven polder

The negotiation support tools were tested as part of the planning process of the Bodegraven polder, a peat meadow area in the Netherlands where water tables are controlled. The polder is located in the centre of the 'Groene Hart' (Green Heart), the largest national landscape of the Netherlands (Figure 2). With an area of 4672 ha, this typical polder area is part of a water-rich region with agriculture, nature and recreation as primary activities. It consists predominantly of peat meadows, originating from peat lands drained in the thirteenth to fifteenth centuries and currently used for commercial dairy farming, but also important for their high natural and landscape values. There are several problems to be addressed in Bodegraven: ground subsidence, preservation of the peat meadow landscape, inefficient water management, poor water quality and the changing economic position of dairy farming (Jansen *et al*. 2007, Querner *et al*. 2008, Woestenburg 2009). Multiple stakeholders such as the local water board, the city of Bodegraven, the province of South Holland, farmers' and nature conservation organizations as well as individual farmers, residents and recreational visitors are involved.

Land drainage causes soil subsidence, which increases the need for further drainage and so on. At some point this cycle has to stop. Lowering of water tables becomes too expensive or even impossible as ground levels continue to fall even further below sea level at an unprecedented rate. Consequently, the provincial authorities have started a planning process to change both water management and land use in the area. Water management is the driving force within this process and land use has to adapt to changing water conditions (Strategiegroep Gouwe Wiericke 2007). As part of the reallocation of land use in the polder, the provincial authorities devised long-term policies that aim to create 860 ha of nature and 1600 ha of land for extensive agriculture. This means that agricultural land must be purchased for conversion to nature and subsidies must be made available to support the transition to extensive agriculture.

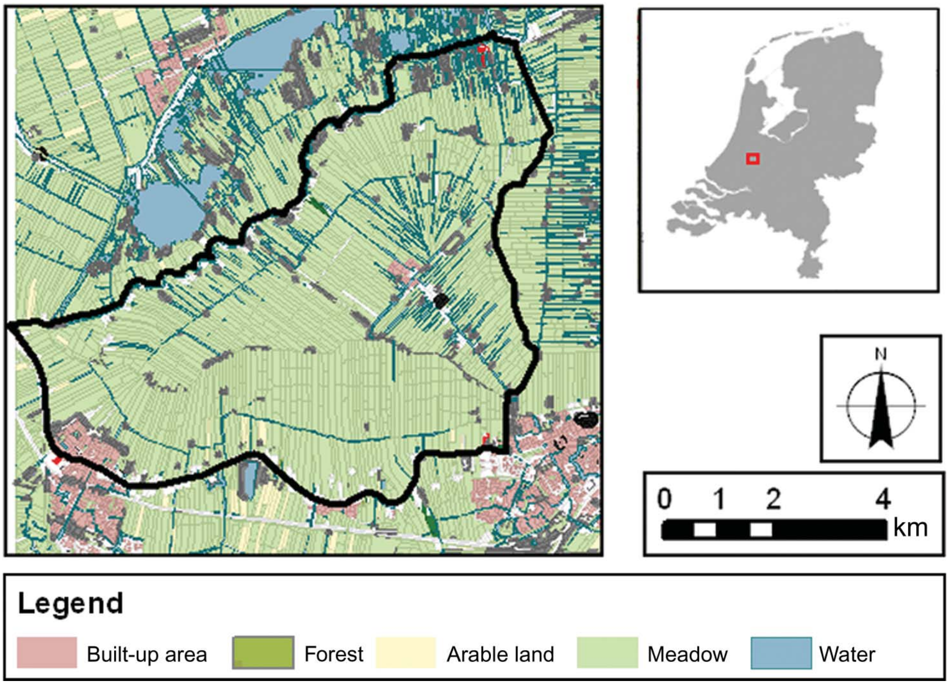

Figure 2. The Bodegraven polder, the Netherlands.

After consultation with the stakeholders, four objectives were identified: (1) profitability of intensive agriculture, (2) minimization of land subsidence, (3) maximization of the visual quality of the landscape and (4) maximization of the natural value of the area. Each objective includes several criteria, such as 'meadow birds', 'species-rich grasslands' and 'marsh birds' for natural values. The score for each criterion is determined by both land use and water level. Three types of land use are identified: intensive agriculture, extensive agriculture and nature. Water level is divided into 10 levels in centimetres below ground level: (0, 0–10, 10–20, . . ., 80–90).

In preparation for the negotiation workshop, an analysis workshop was organized to assess each combination of land use and water level for all criteria and to set the criterion weights. Fifteen experts from a wide range of disciplines involved in peat meadow research participated in this workshop. Together these experts covered all criteria included in the four objectives. As a first step, value maps for all criteria were presented to the experts. Feedback from the experts was used to reassess the land use–water level combinations. Next, the criterion weights were used to generate aggregated value maps for each objective. These maps were fed back to the experts and corrections were made where necessary. A full report of the approach can be found in Janssen *et al*. (in press). Results of this workshop and the list of experts were presented during the introduction of the negotiation workshop. Both outcomes were considered to be sufficiently credible to be used in negotiation.

4.2. Negotiation support tool

The tools presented in Section 3 constitute two different ways to support identification of polygons, which represent individual parcels, to be considered for change of land use

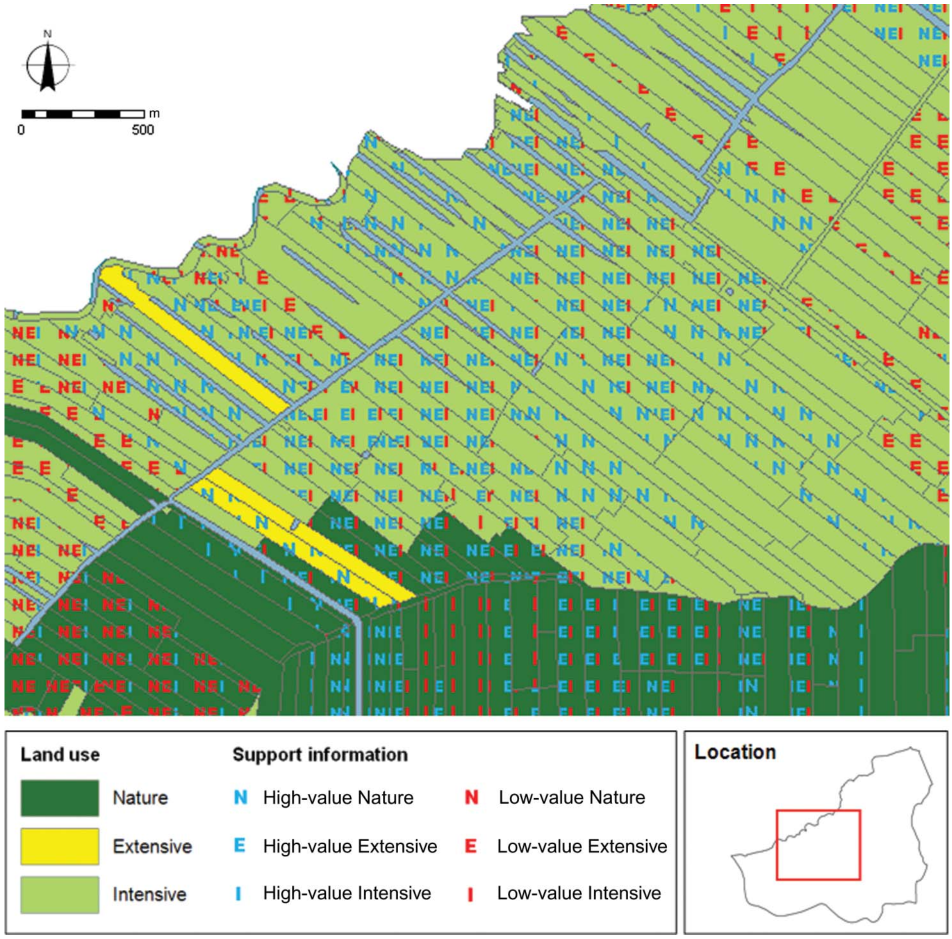

Figure 3. Negotiation support on part of the land use map of Bodegraven. Map shows Nature (dark green), Intensive agriculture (light green) and Extensive agriculture (light green). Blue and red letters indicate high (blue) and low (red) values (blue) for Nature (N), Extensive agriculture (E) and Intensive agriculture (I) of an individual parcel.

(Figure 1). The 'best & worst tool' was selected for Bodegraven polder because policy goals for this type of land use planning are usually set in terms of area size per land use. The participants enter these policy goals in hectares and the tool produces a negotiation map. On the basis of the area sizes specified for the three types of land use, the negotiation map (Figure 3) shows high-value (blue) and low-value (red) parcels for each of the three land uses: Nature (N), Extensive agriculture (E) and Intensive agriculture (I). For example, a sequence of characters 'N E I', coloured respectively blue, blue and red, indicates that a parcel falls within the high-value area for Nature and Extensive agriculture and within the low-value area for Intensive agriculture. If these parcels are currently in use for intensive agriculture, they make good candidates for exchange. Parcels that are not within the specified limits do not show any 'N E I' information on them. The MCA results for the entire study area are plotted into a bar chart, which is presented on a separate display. Five bars appear in the chart, four of which represent the scores for four objectives and one the total score. If the participants change the land use of parcels as a result of the negotiations, the plan will be automatically reassessed in real time.

4.3. Setup of negotiation workshop

The process of achieving a consensus plan takes place during a face-to-face workshop. The half-day workshop consists of interactive sessions in which stakeholders are asked collectively to improve a reference plan with the help of negotiation support tools, which are linked to an interactive mapping device called the 'Touch table'. The 'Touch table' is a large touch screen that allows simultaneous input from a maximum of four users. Participants touch the table with their fingers to change the land use of one or more parcels. Figure 4 shows the workshop hardware setup, which includes a laptop, the Touch table and a separate screen. The software comprises MCA tools for dynamic plan evaluation, tools to support trade-off identification and drawing tools to change land uses on the map (Arciniegas and Janssen 2009). The tools were developed with CommunityViz Scenario 360 (http://www.communityviz.com/, accessed April 2007).

Nine steps are taken to generate consensus on a land use plan during a typical interactive session, as illustrated in Figure 5. (1) The session starts with a reference land use plan presented on the Touch table. (2) The participants select area sizes for high value and/or low value for one or more objectives. (3) The routine selects and highlights on the map those parcels that meet the selection conditions. (4) Feedback on trade suitability for one or all objectives is displayed on selected parcels on top of the land use map (Figure 3). This process is repeated until parcels potentially favourable for an exchange are identified. (5) With the feedback overlaid on parcels, the participants can focus on key spots across the polder and negotiate land use trades. (6) These exchanges are implemented by painting new land uses on parcels using the Touch table. The participants use their fingers to select a land

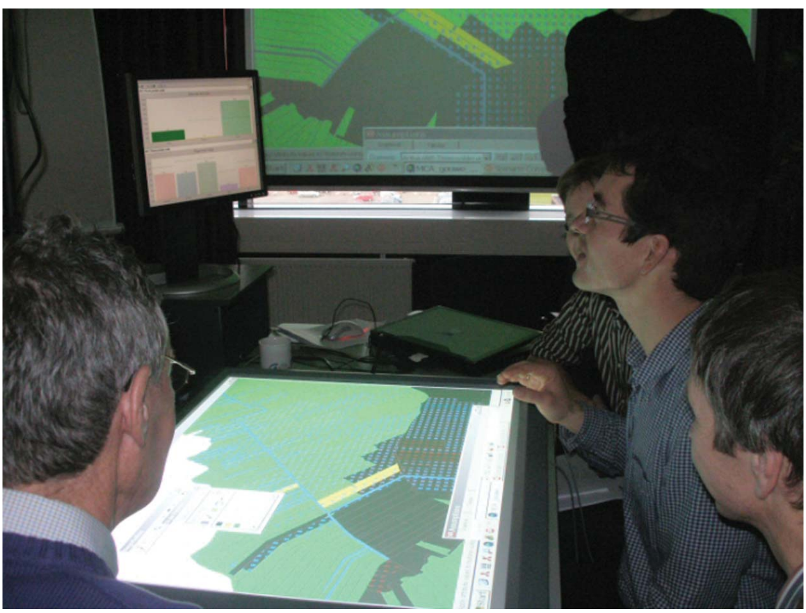

Figure 4. Workshop hardware setup: Touch table and separate screen with support information.

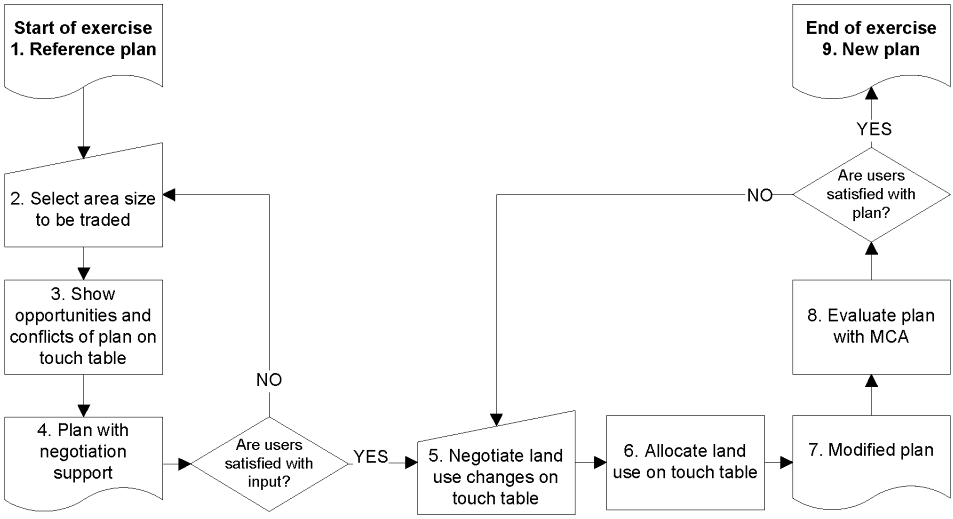

Figure 5. Flowchart of the process followed in an interactive session of a negotiation workshop.

use class and then allocate it to selected parcels. (7) As land uses of parcels are changed, a new land use plan is generated. (8) The qualities of this provisional plan are reassessed with MCA in real time. These results are presented as bar charts representing MCA scores and are available on the separate screen together with the number of exchanged hectares. It is possible to return to steps 2, 3, 4 and 5 to refine selection criteria during new rounds of negotiations. The process of specifying input, trading, reallocating and reassessing continues until the participants are satisfied with the new plan and its qualities. (9) This new consensus plan marks the end of the session.

4.4. Use of negotiation tool

A negotiation workshop was held as part of the planning process of the Bodegraven polder. Participants of the workshop were experts involved in research about peat meadows in the region. The workshop included two parallel interactive sessions with two groups of participants working on two separate Touch tables. The purpose of the workshop was to assess the extent to which the tool can improve the qualities of a reference plan (see Figure 6). Both sessions were held simultaneously, for the same length of time and under the same conditions. In each session a group of three participants used the negotiation tools collectively to generate, within 90 minutes, a consensus land use plan that meets long-term provincial goals. Each participant was asked to play a stakeholder role from the three possible roles (farmers' organizations, agricultural nature organizations, nature organizations) and increase the quality of a specific objective (agriculture, landscape, nature, respectively). Both groups were asked to increase their individual objective and the total quality of the reference plan as they tried to achieve long-term provincial policy goals in hectares for each land use.

Long-term provincial policies aim to create 860 ha of nature and 1600 ha of extensive agriculture in the Bodegraven polder. The province of South Holland has already bought a substantial part of these 860 ha and plans to buy the remainder in the coming years. As a result of the change in water management, not all of the acquired land is in the right

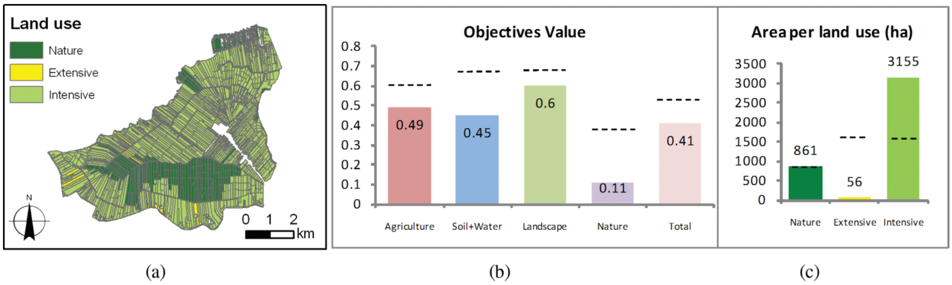

Figure 6. Start situation for the negotiation session: (a) start land use map; (b) aggregated objective values and total value of the start land use map; (c) area size per land use type. Dashed lines indicate the maximum values under the ground water level conditions in (b) and the policy goals set for the three land use types in (c).

location. This means that agricultural land must be bought for conversion into nature and some land already bought can be sold back to agriculture (Strategiegroep Gouwe Wiericke 2007). The assignment for the participants was as follows:

- Allocate 860 ha of nature.
- Allocate 1600 ha of extensive agriculture and 1600 ha of intensive agriculture.
- Maximize the values of the four objectives and the total value.

Figure 7a zooms in on a part of Figure 7a, in which parcels are used for intensive agriculture and nature. The participant with an interest in nature uses the interface to retrieve only the best and worst 861 ha nature in the polder. A similar procedure is followed by a participant with an interest in intensive agriculture. With the input of both participants,

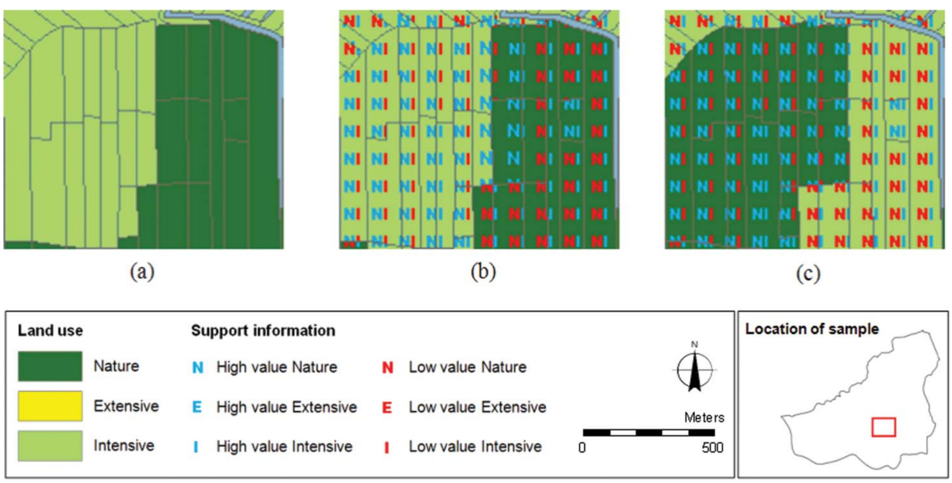

Figure 7. A land use exchange between Intensive agriculture and Nature: (a) a portion of the polder showing land uses Intensive agriculture and Nature allocated to parcels. (b) With the participant's input, support information is displayed on top of the parcels to facilitate the identification of potential trades. (c) This feedback on parcels is used to show participants those parcels whose land uses can be exchanged by painting a new land use.

feedback is displayed on parcels. Figure 7b shows blue N's and red I's overlaid on some parcels on the left currently used for intensive agriculture, indicating that these parcels are valuable for nature (blue N's) and not so for intensive agriculture (red I's). Likewise, some parcels on the right currently used for nature are valuable for intensive agriculture (as indicated by blue I's) and less valuable for nature (as indicated by red N's). These parcels are potentially suitable for an exchange that is favourable for both nature and agriculture. Both participants thus agree on the exchange and proceed to reallocate land use with the drawing tools on the Touch table. Figure 7c shows that nature has been reallocated to parcels with a high value for nature and low for agriculture; intensive agriculture is reallocated similarly. This exchange will likely increase the value for both nature and agriculture as well as the overall value.

4.5. Results of negotiations

Once the two sessions were completed, each group presented their consensus plan, which was followed by a discussion about their underlying ideas and the negotiation support provided. Figure 8 shows the two maps generated by the participants in each session and the qualities of both plans. The spatial distribution of land use on both plans differs quite significantly. By comparing the qualities of the two plans generated by both groups with those of the reference plan, it is clear that both groups succeeded in improving the land use situation for each evaluation objective and the total aggregated score (see Figure 9). Both groups found it difficult to reach the target of 1600 ha of extensive agriculture. Both groups improved the reference plan by similar percentages: the first group from 0.41 to 0.48 and the second from 0.41 to 0.47. Both groups were closely monitored during the sessions and parts of the process were video recorded. A feedback session at the end provided a qualitative impression of the approach and usefulness of the tools. To test approach and tools more systematically, the same exercise was repeated in 10 experimental sessions with three participants in each session. Participants were recruited from the international M.Sc. programme in environment and resource management of the VU University Amsterdam. The participants were asked to answer a number of survey questions related to their background and to the various tasks they had to perform. A full report of both the experiment and surveys can be found in Arciniegas *et al.* (in press).

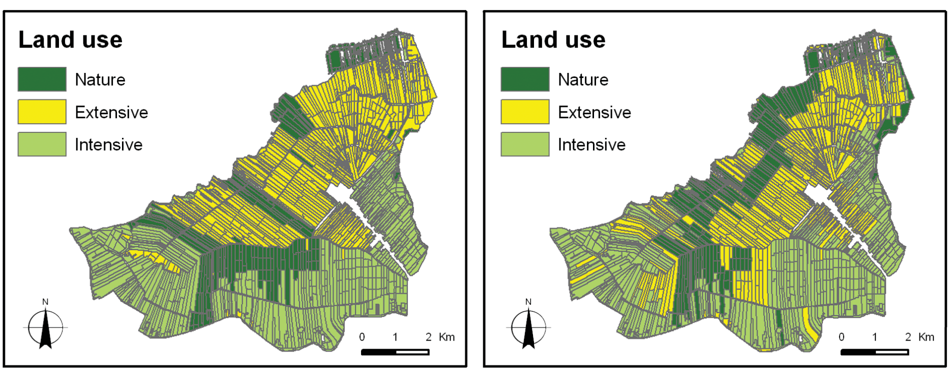

Figure 8. Land use plans developed simultaneously by two stakeholder groups during a negotiation workshop.

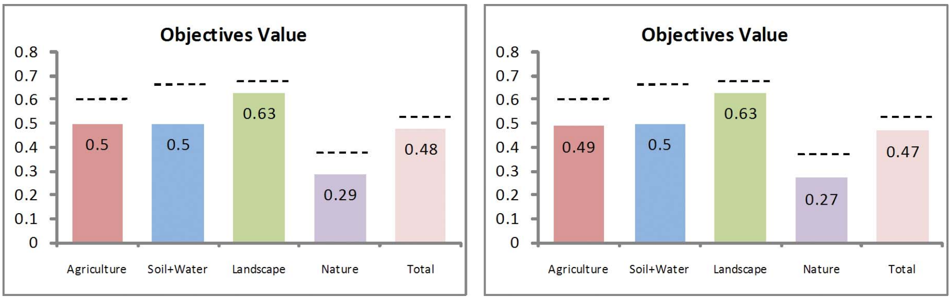

Figure 9. Objective and total values of the two land use plans. Dashed lines on each bar indicate the theoretical maximum value for each objective and total values.

5. Conclusions

This article focused on the use of map-based MCA to develop a negotiation support tool for land use allocation. In Section 1 three research questions were posed:

- Can map-based MCA be used to evaluate and communicate qualities of land use plans?
- Can map-based MCA be used to support negotiation on land use allocation?
- How do participants interact with the tool?

5.1. Map-based MCA

The analysis presented in Section 4.1 begins with a number of maps that show the value of each parcel for 10 criteria on a 1–10 scale. All information on these maps is potentially relevant for supporting negotiation. MCA is used to structure and manage this information in a way that it can be used effectively by the negotiators. Participants used the separate screen with MCA results to discover how land use changes influenced the MCA scores. This required no further explanation. The only question asked was how the dotted line indicating the maximum value was calculated. Results from the survey revealed that 56% of the respondents considered the MCA scores to be useful or very useful and that 66% considered these scores to be easy or very easy to use.

The definition of the criteria and setting of the weights were carried out in a special expert workshop (see Section 4.1). The results of this workshop and the list of experts were presented during the introduction of the negotiation workshop. Given the list of experts, the results were considered sufficiently credible to be used in negotiation. In addition to the aggregated information presented on the 'Touch table', underlying information, such as value maps for individual criteria and objectives, was presented as paper maps on the walls around the table. Video records of the session revealed that negotiators ignored the paper maps although participants agreed that the information was relevant for the negotiation.

5.2. Use of the interactive tool

Negotiators found the Touch table easy to use and sitting around the table allowed for learning by doing. Even users who do not really understand the underlying MCA get a feel for the implications of the method during the negotiation. After a short introduction, participants were able to perform the tasks without further support. Both groups continued the negotiations for 90 minutes without interruptions. At the start, participants experimented with the tool by changing land uses while observing the impact of these changes. In the negotiation process, the end result is reached in a large number of small steps that can all be reversed if needed. By observing the impact of each change, the participant gets a feel for the implications of the method. The survey showed that 62% of the test group considered the tasks to be easy or very easy to perform. Over 73% of all participants found the support provided to be useful or very useful. Positive aspects of the tool mentioned were as follows: learning by doing is stimulated; involvement is increased; and responsibility is better divided.

The negotiation tool requires input from the participants. The output provided combines the quantitative information stored in the tool with knowledge and ideas in the minds of the participants. If a model could be constructed that perfectly represents the knowledge and ideas of the participants, then this input could be replaced by an optimization model. Such a model could then generate the plan that theoretically has the highest value. In practice, developing such a perfect model is not possible. Some objectives are not explicit and only exist in the minds of the negotiators; others are impossible to translate into a formal model. In using the tool, participants are prompted to combine their ideas and knowledge with the information provided by the tool.

5.3. Results

It is important to frame the assignment in such a way that it is perceived as fair by the negotiators and allows room for give-and-take for all participants. In two test runs, the problem was framed as an allocation of 800 ha of new nature at the expense of existing agriculture. This automatically implied that the exercise had one winner and two losers. Participants in these test runs argued that the setting was unfair and were reluctant to cooperate. As a result, the problem was reframed as a reallocation of 800 ha of existing nature. As the allocation at the start of the negotiation was suboptimal, there was something to win for all negotiators. This proved to be important for the commitment of the negotiators to the process.

The participants were asked to maximize the objective values and total value. Looking at these values, both teams managed to reach almost the same increase in objective values and total value. However, the maps produced by both teams showed large differences. This was partly due to the differences in local knowledge between the groups. However, to a much greater extent it was due to the fact that not all objectives could be included in the formal model. More abstract objectives linked to the visual and cultural quality of the area proved difficult to make operational but definitely played a role in the minds of the negotiators. More work will be done to extend the current MCA model with more quantifiable definitions for such objectives. Fuzzy methods, specifically membership functions, could be an alternative to render these objectives operational (e.g. Ekmekçioğlu *et al.* 2010). These methods are argued to be adequate to deal with definitions that are linked to human perception and opinions (Hajkowicz and Collins 2007, Bishop *et al*. 2009). Negotiators in both teams showed a cooperative attitude. They had the intention of doing a good job. The successful use of the tool depends very much on such a cooperative attitude. The experiments showed that the quality of the results was linked to the level of cooperation within the group. As such, it is very much a product of the Dutch way of decision-making. In situations of sharp conflict, or a more power-based style of decision-making, it is questionable whether the tool would be as useful.

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